Advanced C++

*

declare pointers:

`Rectangle *pointerToRect = &aRect;`

`pointerToRect` is a *pointer to Rectangle*

initially points to `aRect`

dereference pointers:

`(*pointerToRect).size`, `pointerToRect->size`,

`*pointerToRect = anotherRect`

all modify pointed-to object (`aRect`)

&

declare references:

```
Rectangle &refToRect = aRect;,
void print(const Rectangle &theRect);
```

`refToRect`, `theRect` are *references to Rectangle*

address-of:

```
pointerToRect = &refToRect;
```

`&value` is the address of `value`

recall: reference v pointer

pointer — explicitly derference, can reassign

reference — “bound” to object on creation, always refers to it

typical implementation of both in asm: pointer

typed pointers

```
double Z = 26.0;
int *pointerToInt = &Z;   // ERROR
```

"`cannot convert 'double*' to 'int*' in initialization`"

C++ cares about type (but just addresses in assembly)

dereference example (1)

```
int n = 26;
int *somePointer = &n;

cout << somePointer << endl;
cout << *somePointer << endl;
```

dereference example (1)

```
int n = 26;
int *somePointer = &n;

cout << somePointer << endl;
cout << *somePointer << endl;
```

example output: (address will vary...)

```
0x7fff35fc3fe4
26
```

dereference example (2)

```
int n = 26;
int *somePointer = &n;
*somePointer = 45;

cout << somePointer << endl;
cout << *somePointer << endl;
```

dereference example (2)

```
int n = 26;
int *somePointer = &n;
*somePointer = 45;

cout << somePointer << endl;
cout << *somePointer << endl;
```

example output: (address will vary...)

```
0x7fff35fc3fe4
45
```

dereference example (3)

```
ListNode *ptr1, *ptr2;
ptr1 = new ListNode;
ptr2 = new ListNode

bool result1 = (ptr1 == ptr2);
bool result2 = (*ptr1 == *ptr2);
```

dereference example (3)

```
ListNode *ptr1, *ptr2;
ptr1 = new ListNode;
ptr2 = new ListNode

bool result1 = (ptr1 == ptr2);
bool result2 = (*ptr1 == *ptr2);
```

`result1` definitely false (different addresses)

`result2` probably true (depends on `ListNode::operator==`)

reference example

```
int y = 5;
int &x = y;
cout << x << endl;
cout << &x << endl;
cout << &y << endl;
x = 15;
cout << y << endl;
```

reference example

```
int y = 5;
int &x = y;
cout << x << endl;
cout << &x << endl;
cout << &y << endl;
x = 15;
cout << y << endl;
```

---

example output (address will vary…)

```
5
0x7ffeeda220d4
0x7ffeeda220d4
15
```

can't change adderss stored in x

pointers to pointers

```
int main() {
    Animal cow;
    Animal* cowPtr1 = &cow;
    Animal** cowPtr2(&cowPtr1);
    Animal*** cowPtr3 = &cowPtr2;
    ...
}
```

pointers to pointers

```
int main() {
    Animal cow;
    Animal* cowPtr1 = &cow;
    Animal** cowPtr2(&cowPtr1);
    Animal*** cowPtr3 = &cowPtr2;
    ...
}
```

---

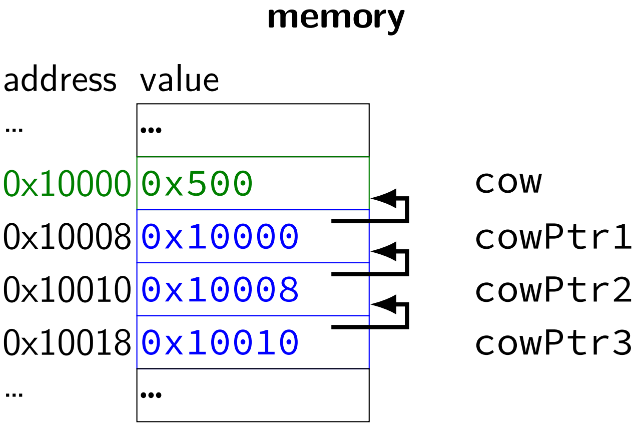
cow = Animal

cowPtr1 = pointer to Animal

cowPtr2 = pointer to (pointer to Animal)

cowPtr3 = pointer to pointer to (pointer to Animal)

example memory layout



ref to pointer v pointer to pointer

```
void insert(TreeNode*& n, int value) {
    if (n == NULL)
        n = new TreeNode(value);
    else if (value < n->value)
        insert(n->left, value);
    else if (value > n->value)
        insert(n->right, value);
}
```

```
void insert(TreeNode** n, int value) {
    if (*n == NULL)
        *n = new TreeNode(value);
    else if (value < n->value)
        insert(&(n->left), value);
    else if (value > n->value)
        insert(&(n->right), value);
}
```

ref to pointer v pointer to pointer

```
void insert(TreeNode*& n, int value) {
    if (n == NULL)
        n = new TreeNode(value);
    else if (value < n->value)
        insert(n->left, value);
    else if (value > n->value)
        insert(n->right, value);
}
```

```
void insert(TreeNode** n, int value) {
    if (*n == NULL)
        *n = new TreeNode(value);
    else if (value < n->value)
        insert(&(n->left), value);
    else if (value > n->value)
        insert(&(n->right), value);
}
```

ref to pointer v pointer to pointer

```
void insert(TreeNode*& n, int value) {
    if (n == NULL)
        n = new TreeNode(value);
    else if (value < n->value)
        insert(n->left, value);
    else if (value > n->value)
        insert(n->right, value);
}
```

```
void insert(TreeNode** n, int value) {
    if (*n == NULL)
        *n = new TreeNode(value);
    else if (value < n->value)
        insert(&(n->left), value);
    else if (value > n->value)
        insert(&(n->right), value);
}
```

by ref versus by value

```
void insert(TreeNode*& n, int value) {
    if (n == NULL)
        n = new TreeNode(value);
    else if (value < n->value)
        insert(n->left, value);
    else if (value > n->value)
        insert(n->right, value);
}
```

```
TreeNode *insert(TreeNode* n, int value) {
    if (n == NULL)
        return new TreeNode(value);
    else if (value < n->value) {
        n->left = insert(n->left, value);
        return n;
    } else if (value > n->value) {
        n->right = insert(n->right, value);
        return n;
    }
}
```

by ref versus by value

```
void insert(TreeNode*& n, int value) {
    if (n == NULL)
        n = new TreeNode(value);
    else if (value < n->value)
        insert(n->left, value);
    else if (value > n->value)
        insert(n->right, value);
}
```

```
TreeNode *insert(TreeNode* n, int value) {
    if (n == NULL)
        return new TreeNode(value);
    else if (value < n->value) {
        n->left = insert(n->left, value);
        return n;
    } else if (value > n->value) {
        n->right = insert(n->right, value);
        return n;
    }
}
```

by ref versus by value

```
void insert(TreeNode*& n, int value) {
    if (n == NULL)
        n = new TreeNode(value);
    else if (value < n->value)
        insert(n->left, value);
    else if (value > n->value)
        insert(n->right, value);
}
```

```
TreeNode *insert(TreeNode* n, int value) {
    if (n == NULL)
        return new TreeNode(value);
    else if (value < n->value) {
        n->left = insert(n->left, value);
        return n;
    } else if (value > n->value) {
        n->right = insert(n->right, value);
        return n;
    }
}
```

several memory allocation problems

BROKEN:

```
void someFunc(int *somePointer) {
    int someval(3);
    somePointer = &someVal;
}

int main() {
    int *firstPointer;
    someFunc(firstPointer);
    cout << *firstPointer << endl;
    return 0;
}
```

several memory allocation problems

BROKEN:

```
void someFunc(int *somePointer) {
    int someval(3);
    somePointer = &someVal;
}

int main() {
    int *firstPointer;
    someFunc(firstPointer);
    cout << *firstPointer << endl;
    return 0;
}
```

---

pointer to deallocated memory — need `new`

several memory allocation problems

BROKEN:

```
void someFunc(int *somePointer) {
    int someval(3);
    somePointer = &someVal;
}

int main() {
    int *firstPointer;
    someFunc(firstPointer);
    cout << *firstPointer << endl;
    return 0;
}
```

---

pointer to deallocated memory — need `new`

pass by value, not by reference

several memory allocation problems (fixed?)

```
void someFunc(int *&somePointer) {
    somePointer = new int(3);
}

int main() {
    int *firstPointer;
    someFunc(firstPointer);
    cout << *firstPointer << endl;
    return 0;
}
```

several memory allocation problems

BROKEN:

```
void someFunc() {
    double *aliasPointer;
    aliasPointer = new double(6.27);
    cout << *aliasPointer << endl;
}
```

several memory allocation problems

BROKEN:

```
void someFunc() {
    double *aliasPointer;
    aliasPointer = new double(6.27);
    cout << *aliasPointer << endl;
}
```

---

memory leak — never `deleted`

several memory allocation problems

BROKEN:

```
void someFunc() {
    double duration = 3.14;
    {
        double * somePtr;
        {
            somePtr = &duration;
        }
    }
    cout << *somePtr << endl;
    return 0;
}
```

several memory allocation problems

BROKEN:

```
void someFunc() {
    double duration = 3.14;
    {
        double * somePtr;
        {
            somePtr = &duration;
        }
    }
    cout << *somePtr << endl;
    return 0;
}
```

---

syntax error: `somePtr` no longer exists

several memory allocation problems

BROKEN:

```
int main() {
    int * anotherPtr;
    {
        int someVal(8);
        cout << *anotherPtr << endl;
        anotherPtr = &someVal;
    }

    return 0;
}
```

several memory allocation problems

BROKEN:

```
int main() {
    int * anotherPtr;
    {
        int someVal(8);
        cout << *anotherPtr << endl;
        anotherPtr = &someVal;
    }

    return 0;
}
```

---

undefined behavior: accessing uninitialized pointer

several memory allocation problems

BROKEN:

```
void someFunc(int *somePointer) {
    int someVal(12);
    {
        int anotherVal(16);
        somePointer = &anotherVal;
    }
}

int main() {
    int * yetAnotherPtr;
    someFunc(yetAnotherPtr);
    cout << *yetAnotherPtr << endl;
    return 0;
}
```

a correct example

```
int main() {
    float * somePtr;
    somePtr = new float(3.14);
    cout << *somePtr << endl;
    delete somePtr;
    return 0;
}
```

a correct example

```
void someFunc() {
    int *aliasPtr;
    aliasPtr = new int(25);
    cout << *aliasPtr << endl;
}

int main() {
    int * somePtr;
    somePtr = new int(3);
    someFunc();
    cout << *somePtr << endl;
    return 0;
}
```

a correct example

```
void someFunc() {
    int *aliasPtr;
    aliasPtr = new int(25);
    cout << *aliasPtr << endl;
}

int main() {
    int * somePtr;
    somePtr = new int(3);
    someFunc();
    cout << *somePtr << endl;
    return 0;
}
```

memory leaks

C++ inheritence example (1)

```
class Name {
public:
    Name();
    ~Name();
    void setName(const string &name);
    void print() {
        cout << myName << endl;
    }
private:
    string myName;
};
```

C++ inheritence example (2)

```
class Contact : public Name {
public:
  Contact() {
      myAddress = ""
  }

  ~Contact() {
  }

  void setAddress(const string &address) {
    myAddress = address;
  }

  void print() {
    Name::print();
    cout << myAddress << endl;
  }
private:
  string myAddress;
}
```

C++ inheritence example (2)

```
class Contact : public Name {
public:
  Contact() {
      myAddress = ""
  }

  ~Contact() {
  }

  void setAddress(const strin
    myAddress = address;
  }

  void print() {
    Name::print();
    cout << myAddress << endl;
  }
private:
  string myAddress;
}
```

```
public class Contact
    extends Name {
  ...
  void print() {
    super.print();
    ...
  }
}
```

C++ inheritence example (2)

```
class Contact : public Name {
public:
  Contact() {
      myAddress = ""
  }

  ~Contact() {
  }

  void setAddress(const strin
    myAddress = address;
  }

  void print() {
    Name::print();
    cout << myAddress << endl;
  }
private:
  string myAddress;
}
```

```
public class Contact
    extends Name {
  ...
  void print() {
    super.print();
    ...
  }
}
```

contact usage (1)

```
int main(void) {
    Contact c;
    c.SetName("John␣Doe");
    c.SetAddress("009␣Olsson␣Hall");
    c.print();
}
```

contact usage (2)

```
int main(void) {
    Contact c;
    Name &r = c;
    r.SetName("John␣Doe");
    // or:
    Name *p = &c;
    p->SetName("John␣Doe");
    c.SetAddress("009␣Olsson␣Hall");
    c.print();
}
```

memory layout

address	value	
...	...	
0x10000	"John Doe"	c.myName
0x10020	"009 Olsson Hall"	c.myAddress
0x10040	0x10000	r (ref. to c as Name)
...	...	

c.myName and c.myAddress: Contact c

memory layout

address	value	
...	...	
0x10000	"John Doe"	c.myName
0x10020	"009 Olsson Hall"	c.myAddress
0x10040	0x10000	r (ref. to c as Name)
...	...	

c.myName: as Name

c.myName, c.myAddress: Contact c

inheritence in C++

`Contact` is child of parent `Name`

has member variables, functions of parent

...with same layout in memory

- parent's methods work without changing assembly
- can get reference/pointer to `Name` from `Contact`

add new member functions/variables

inheritence and constructors, etc.

```
class Parent {
public:
    Parent() { cout << "Parent()\n"; }
    ~Parent() { cout << "~Parent()\n"; }
};
class Child : public Parent {
public:
    Child() { cout << "Child()\n"; }
    ~Child() { cout << "~Child()\n"; }
};
int main() {
    Child var;
    cout << "in␣main()\n";
}
```

```
Parent()
Child()
in main()
~Child()
~Parent()
```

construction/destruction order

parent part constructed first

then child

child part destroyed first

then parent

arguments to parent constructors?

```
class Parent {
public:
    Parent(int x) { cout << "Parent(" << x << ")\n"; }
    ~Parent() { cout << "~Parent()\n"; }
};
class Child : public Parent {
public:
    Child(int x) : Parent(x + 1) { cout << "Child(" << x << ")\n"; }
    ~Child() { cout << "~Child()\n"; }
};
int main() {
    Child var(100);
    cout << "in main()\n";
}
```

```
Parent(101)
Child(100)
in main()
~Child()
~Parent()
```

multiple inheritence

```
class Sphere : public Shape, public Comparable,
               public Serializable {
    // ...
};
```

multiple inheritence

```
class Sphere : public Shape, public Comparable,
               public Serializable {
    // ...
};
```

sort of like this Java code:

```
public class Sphere extends Shape
        implements Comparable, Serializable {
    // ..
}
```

but — `Comparable`, `Serializable` might have thier own member variables and implemented methods

C++ defaults to static dispatch (1)

```
class Parent {
public:
    void print() { cout << "Parent::print()\n"; }
};
class Child : public Parent {
public:
    void print() { cout << "Child::print()\n"; }
};
Parent* getParent() { return new Child; }
int main() {
    Parent *p = getParent();
    p->print();
    delete p;
}
```

output:

```
Parent::print()
```

C++ defaults to static dispatch (1)

```
class Parent {
public:
    void print() { cout << "Parent::print()\n"; }
};
class Child : public Parent {
public:
    void print() { cout << "Child::print()\n"; }
};
Parent* getParent() { return new Child; }
int main() {
    Parent *p = getParent();
    p->print();
    delete p;
}
```

output:

```
Parent::print()
```

static versus dynamic dispatch

static dispatch — call method based on compile-time type

dynamic dispatch — call method based on run-time type

C++ defaults to static dispatch (2)

```
class Parent {
public:
    Parent() {cout << "Parent()\n"; }
    ~Parent() { cout << "~Parent()\n"; }
};
class Child : public Parent {
public:
    Child() { cout << "Child()\n"; }
    ~Child() { cout << "~Child()\n"; }
};
Parent* getParent() { return new Child; }
int main() {
    Parent *p = getParent();
    delete p;
}
```

output (*probably*):

```
Parent()
Child()
~Parent()
```

C++ defaults to static dispatch (2)

```
class Parent {
public:
    Parent() {cout << "Parent()\n"; }
    ~Parent() { cout << "~Parent()\n"; }
};
class Child : public Parent {
public:
    Child() { cout << "Child()\n"; }
    ~Child() { cout << "~Child()\n"; }
};
Parent* getParent() { return new Child; }
int main() {
    Parent *p = getParent();
    delete p;
}
```

output (*probably*):

```
Parent()
Child()
~Parent()
```

virtual: ask for dynamic dispatch

`virtual` keyword — ask for dynamic dispatch

not default — because slower:

- static dispatch: just a function call
- dynamic dispatch: lookup correct function first!

virtual methods (1)

```
class Parent {
public:
    virtual void print() { cout << "Parent::print()\n"; }
};
class Child : public Parent {
public:
    void print() { cout << "Child::print()\n"; }
};
Parent* getParent() { return new Child; }
int main() {
    Parent *p = getParent();
    p->print();
    delete p;
}
```

output:

```
Child::print()
```

virtual methods (1)

```
class Parent {
public:
    Parent() {cout << "Parent()\n"; }
    virtual ~Parent() { cout << "~Parent()\n"; }
};
class Child : public Parent {
public:
    Child() { cout << "Child()\n"; }
    ~Child() { cout << "~Child()\n"; }
};
Parent* getParent() { return new Child; }
int main() {
    Parent *p = getParent();
    delete p;
}
```

output:

```
Parent()
Child()
~Child()
~Parent()
```

virtual destructors

required if you call `delete` on a base-class pointer

  (but it's actually an instance of the subclass)

compiler might use destructor to know how much memory to free

  so requied even if destructor "doesn't do anything"

  C++ standard quote: "If the static type of the object to be deleted is different from its dynamic type, the static type shall be a base class of the dynamic type of the object to be deleted and the static type shall have a virtual destructor or the behavior is undefined."

a dynamic call

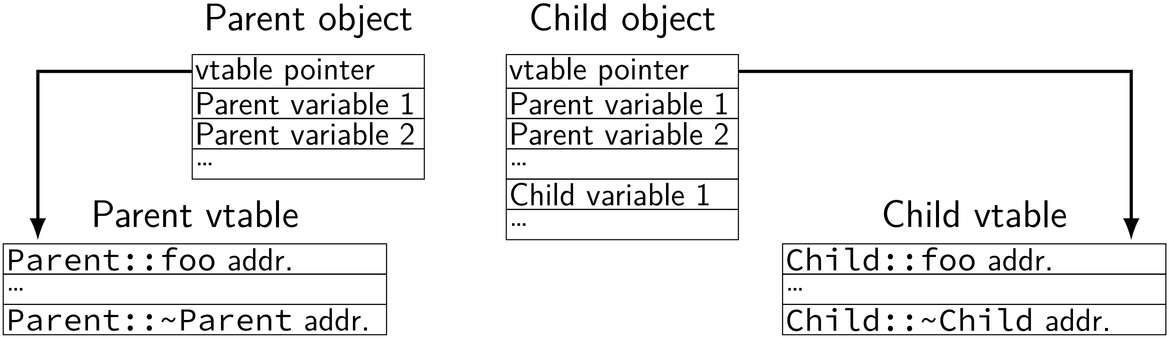
```
class Parent {
public:
    virtual void foo() { ... }
    ...
};
class Child : public Parent {
    virtual void foo() { ... }
    ...
};
Parent *get();  // return Parent or Child
int main() {
    Parent *p = get();
    p->foo();
}
```

What does assembly for `main` look like?

Could call `Parent::foo` or `Child:foo`

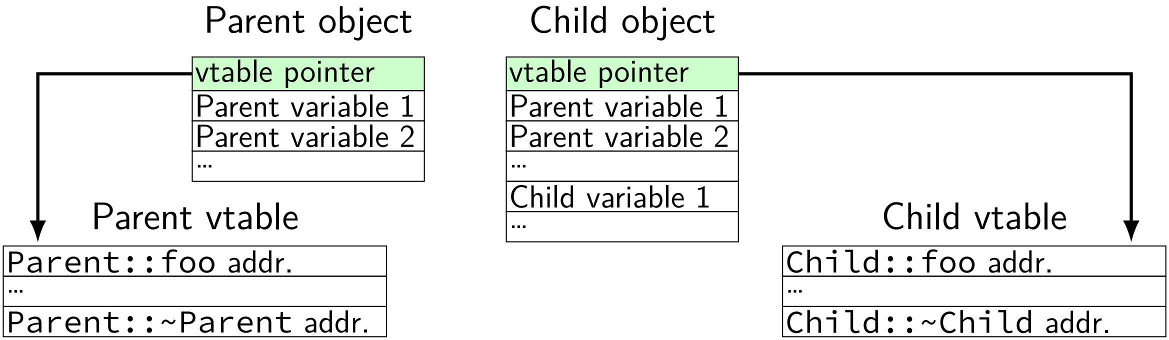
dynamic call: assembly

```
// Parent *p (RAX) = get();
call get
mov rcx, [rax + 0]  // rcx ← "VTable" address
mov rdi, rax        // rdi (this arg) ← p
call [rcx + 0]      // call what rcx points to
```



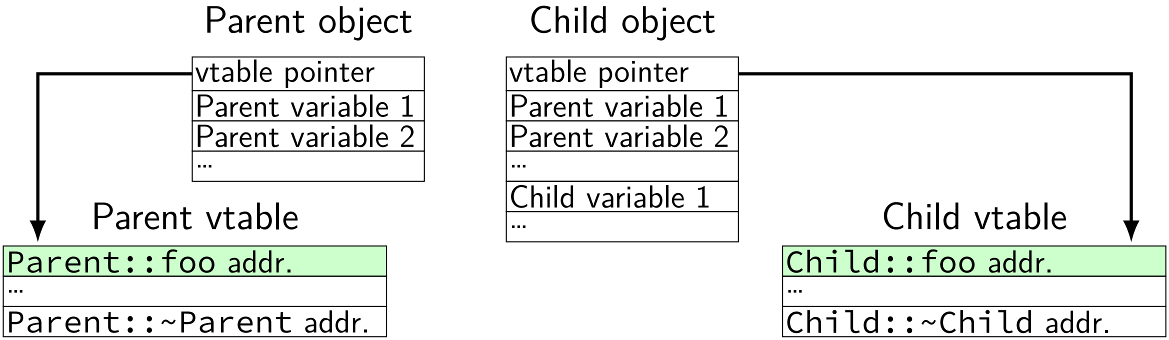
dynamic call: assembly

```
// Parent *p (RAX) = get();
call get
mov rcx, [rax + 0]     // rcx ← "VTable" address
mov rdi, rax           // rdi (this arg) ← p
call [rcx + 0]         // call what rcx points to
```



dynamic call: assembly

```
// Parent *p (RAX) = get();
call get
mov rcx, [rax + 0]   // rcx ← "VTable" address
mov rdi, rax         // rdi (this arg) ← p
call [rcx + 0]       // call what rcx points to
```



vtables during construction

vtable set by constructor call

constructor call order:

- parent vtable set first
- then Parent() constructor run
- overwritten with child vtable
- then Child() constructor run
- ...

rule: never call method before it's type's constructor

pure virtual member functions

```
class Shape {
public:
    virtual void draw() = 0;
}
```

`= 0` — no implementation!

"pure virtual function/method"

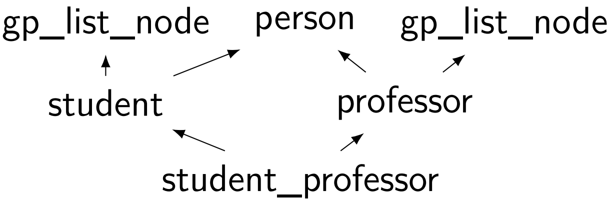
must be overriden to create object

otherwise, "abstract class"

≈ `abstract` in Java

only abstract methods ≈ Java interface

diamands or duplicates



replicated parents (`gp_list_node`)

- one copy each time inherited
- seperate lists of students, professors

shared parents (`person`)

- one copy of attributes (name?) for person

C++ default: replicated inheritence

```
class Parent { public:
    int value;
};
class A : public Parent {};
class B : public Parent {};
class C : public A, public B {};

int main() {
    C c;
    A& as_a = c; B& as_b = c;
    as_a.value = 1; as_b.value = 2;
    cout << as_a.value << "␣" << as_b.value << endl;
}
```

---

output: `1 2` (two copies of `value`)

virtual inheritence: one copy

```
class Parent { public:
    int value;
};
class A : public virtual Parent {};
class B : public virtual Parent {};
class C : public A, public B {};

int main() {
    C c;
    A& as_a = c; B& as_b = c;
    as_a.value = 1; as_b.value = 2;
    cout << as_a.value << "␣" << as_b.value << endl;
}
```

---

output: 2 2 (`as_a.value` same as `as_b.value`)

virtual inheritence: one copy

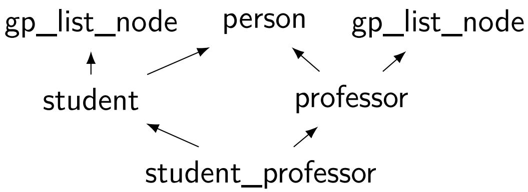
```
class Parent { public:
    int value;
};
class A : public virtual Parent {};
class B : public virtual Parent {};
class C : public A, public B {};

int main() {
    C c;
    A& as_a = c; B& as_b = c;
    as_a.value = 1; as_b.value = 2;
    cout << as_a.value << "␣" << as_b.value << endl;
}
```

---

output: 2 2 (as_a.value same as as_b.value)

declaring a mix




```
class student: public virtual person, public gp_list_node {...};
class professor: public virtual person, public gp_list_node {...};
class student_professor: public professor, public student {...};
```

diamond inheritence and constructors (1)

```
class Parent { public:
    Parent(const char *x) { cout << "Parent(" << x << ")" << endl; }
};
class A : public virtual Parent { public:
    A() : Parent("A") {}
};
class B : public virtual Parent { public:
    B() : Parent("B") {}
};
class C : public A, public B { public:
    C() : Parent("C") {}
};

int main() {
    C c;
}
```

---

output: `Parent(C)`

diamond inheritence and constructors (2)

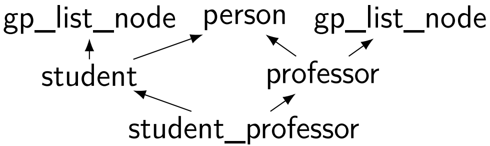
```
class Parent { public:
    Parent() { cout << "Parent()␣[default␣constructor]" << endl; }
    Parent(const char *x) { cout << "Parent(" << x << ")" << endl; }
};
class A : public virtual Parent { public:
    A() : Parent("A") {}
};
class B : public virtual Parent { public:
    B() : Parent("B") {}
};
class C : public A, public B { public:
    C() {}
};

int main() {
    C c;
}
```

---

output: `Parent() [default constructor]`

duplicate layout




```
gp_list_node &getStudentList(student_professor &p) {
    return (gp_list_node &) (student &) p;
}
gp_list_node &getProfessorList(student_professor &p) {
    return (gp_list_node &) (proessor &) p;
}
```

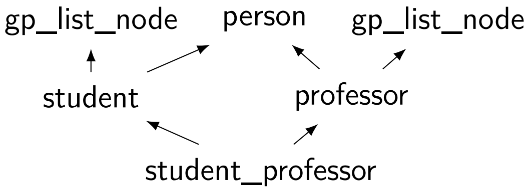
---

example assembly:

```
getStudentList:
    lea rax, [rdi + 8]
    ret
```

```
getProfessorList:
    lea rax, [rdi + 64]
    ret
```

diamond layout



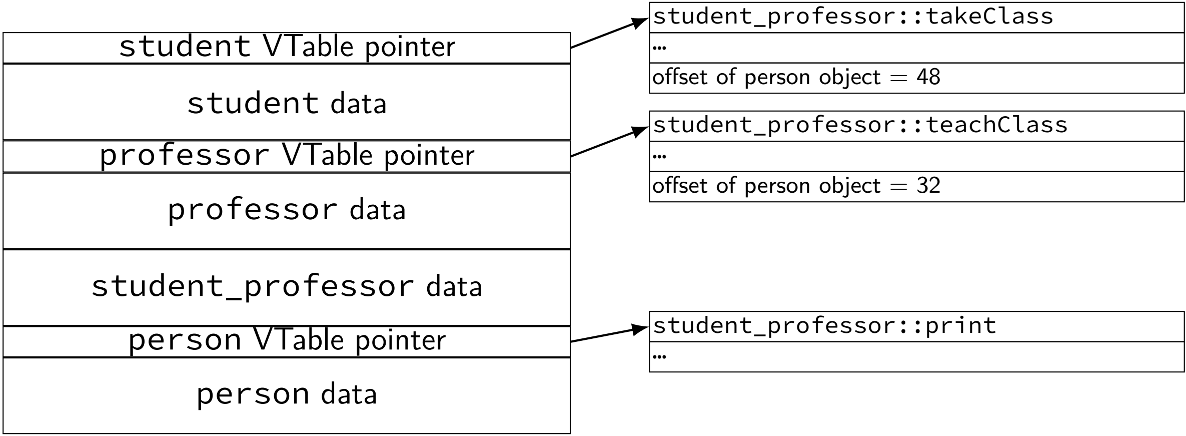

```
(person&) studentProf ==
    (person &) (student &) studentProf ==
        (person &) (professor &) studentProf
```

---

casts need more indirection to implement

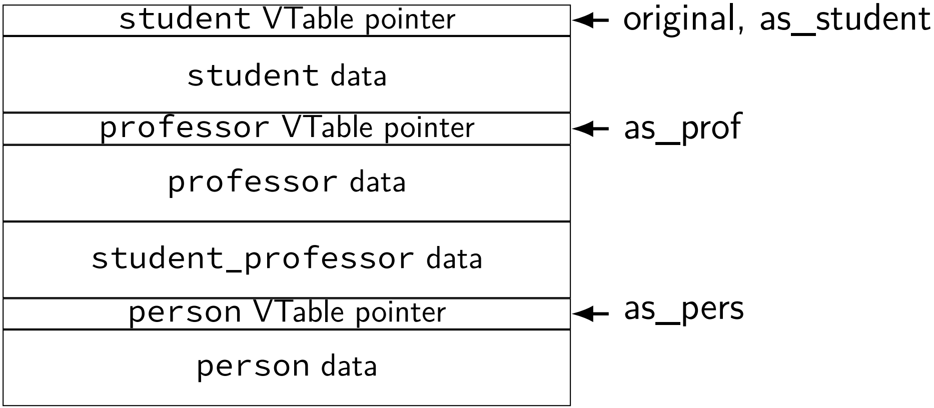
- example: vtable lookup of offset to 'person' fields
- different 'offsets' of object for `professor` versus `student_professor`

a possible layout



a possible layout

```
student_professor *original
     = new student_professor;
student *as_student = original;
professor *as_prof = original;
person *as_pers = original;
```



co-variant arrays

```
String[] a = new String[1];
Object[] aAsObjects = a;
b[0] = new Integer(1);
```

compiles, but throws `ArrayStoreException`

not really an array of objects

non-co-variant containers

```
class Parent {};
class Child : public Parent {};
...
vector<Child *> v;

vector<Parent *> &vAsParent = v;  // DOES NOT COMPILE
```

multiple inheritence style guides

Google C++ style guide:

> "Only very rarely is multiple implementation inheritance actually useful. We allow multiple inheritance only when at most one of the base classes has an implementation; all other base classes must be pure interface classes tagged with the Interface suffix."

Joint Strike Fighter C++ style guide:

> "Stateful virtual bases should be rarely used and only after other design options have been carefully weighed."

C++11 and beyond

C++ standard versions:

- 1997(C++03): `-std=c++98`
- 2003 (C++03): `-std=c++03`
- August 2011 (C++11): `-std=c++11`
- August 2014 (C++14): `-std=c++14`
- March 2017 (C++17): `-std=c++17`
- ??? 2020 (C++20)

notable C++11 features

move constructors and r-value references

  option for moving value from x to y without copying

initialization with braces: `Class name{arg1, arg2, ...}`

foreach loops: `for (int &x: some_vector) {...}`

type inference: `auto it = some_vector.iterator();`

return type at end: `auto foo(int x, int y) -> int;`

`nullptr`

(more) smart pointers

move motivation

```
vector<string> v;
...
v.push_back(getBigString());
```

C++03: this makes a copy of what `getBigString()` returns!

(`push_back` calls the copy constructor)

using move constructors

```
string one = "some␣contents";
string two = std::move(one);
```

---

two contains `"some contents"`

one's contents unspecified

move constructors

```
class DynamicArray {
public:
    ...
    DynamicArray(DyanmicArray &&moveFrom) {
        pointer = moveFrom.pointer;
        size = moveFrom.size;
        moveFrom.pointer = NULL;
        moveFrom.size = 0;
    }
private:
    int *pointer;
    int size;
};
```

using move assignment

```
string one = "some␣contents";
string two = "other␣contents";
two = std::move(one);
```

---

two contains `"some contents"`

one's contents unspecified

move assignment operators

```
class DynamicArray {
public:
    ...
    DynamicArray &operator=(DynamicArray &&moveFrom) {
        if (pointer != NULL)
            delete[] pointer;
        pointer = moveFrom.pointer;
        size = moveFrom.size;
        moveFrom.pointer = NULL;
        moveFrom.size = 0;
        return *this;
    }
private:
    int *pointer;
    int size;
};
```

brace-based initialiation

can now use `{}` to initialize objects:

```
// SomeClass()
SomeClass foo;                      SomeClass foo{};

// SomeClass(const SomeClass &)
SomeClass bar(foo);                 SomeClass bar{foo};

// SomeClass(int, int, int, int)
SomeClass quux(1, 2, 3, 4);         SomeClass quux{1, 2, 3, 4};

// vector<int>(initializer_list<int>)
/* not supported in C++03 */        vector<int> v{0, 1, 2, 3, 4, 5};
```

range-based for loops

```
int array[1000];
....
for (int &x : array) {
    ...
}
```

```
vector<int> v;
...
for (int &x : v) {
    ...
}
```

auto

```
vector<int> v;
auto it = v.begin();
// instead of:
vector<int>::iterator it = v.begin();
```

trailing return types

```
auto foo(int x, int y) -> int { ... }
// instead of:
int foo(int x, int y) { ... }
```

nullptr

`nullptr` is substitue for `0`/`NULL`

typechecks better

`int x = nullptr;` — ERROR
`int x = NULL;` — sets x to 0

unique_ptr

instead of:

```
class Foo {
    ...
    ~Foo() { delete bar; }
    void set() {
        if (bar) delete bar;
        bar = new Bar(...);
    }
    Bar *bar;
};
```

```
class Foo {
    void set() {
        bar.reset(new Bar(...));
    }
    unique_ptr<Bar> bar;
};
```

unique_ptr implementation

```
template <class T> class unique_ptr {
    ...
    T& operator->() { return *value; }
    T& operator*() { return *value; }
    void reset(T* new_value) {
        if (value) delete value;
        value = new-value;
    }
    ~unique_ptr() {
        if (value) delete value;
    }
private:
    T *value;
}
```

the smart pointers

`unique_ptr` — "owns" the object

delete object when pointer goes away/changes

`shared_ptr` — keeps a reference count

delete object when last `shared_ptr` goes away

`weak_ptr` — works with shared_ptr, but doesn't modify reference count

handles circular references

miscellanous C++11/14/17

lambda expressions (closures)

compile-time arithmetic (constexpr)

function attributes

e.g. `[[override]]`: ‘give me an error if this isn’t overriding something’

compile-time assertions

using C++11, etc.

`clang -std=c++11` (or c++14 …)